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YOUNG AND OLDER OBSERVERS SHOW SIMILAR PERCEIVED CONTRAST FUNCTIONS FOR ISOLUMINAT STIMULI

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TECHNICAL REVIEW AND APPROVAL

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This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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Previous research from our laboratory has demonstrated an age-related difference in the perceived brightness of brief, low intensity flashes of light. The purpose of this experiment was to determine if the age-related brightness differences would generalize to isoluminant conditions. Thus, the effect of age on visual system contrast gain was examined by use of sinusoidal grating stimuli with the method of contrast estimation. Ten young and 10 older males (mean ages 20 and 64.5 yrs) viewed counterphase flickered gratings of 0.6 and 6.0 c/deg ranging in contrast from 1 to 50 percent. The resulting linear functions of log perceived contrast as a function of log stimulus contrast showed no age-related differences and suggest equivalent contrast gain with age. These results, placed within the context of previous research, suggest that the largest age-related differences in visual

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19. performance are found when subjects must perform a detection/recognition task that is embedded in a flashing background.

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INTRODUCTION

Age-related differences in the perceived brightness of brief, low intensity flashes of light have been previously reported by Sturr, Van Orden, and Taub (1). As shown in Figure 1, when log perceived brightness was plotted as a function of log stimulus intensity, the data were best fit by two linear functions -- one for low intensity stimuli and one for high intensity stimuli. At high intensities, the slopes of the brightness functions of young and older observers were nearly identical. At low intensities, however, the young observers' brightness function was significantly steeper than the older observers' function. Since the lowest intensity flashes were 0.5 log units above absolute threshold, these results were interpreted as reflecting a difference in response gain between young and older observers for brief, low intensity stimuli.

The finding of a dual-branched brightness function for both age groups supported recent research by Drum (2), indicating that perhaps two mechanisms code brightness. It also signaled the possibility of a selective age-related decrease in the gain output of the mechanisms sensitive to low stimulus intensities. Drum (2) proposed that his results were consistent with the sensitivity and gain characteristics of neurons within the parvo- and magnocellular layers of the lateral geniculate nucleus (3, 4). At low stimulus contrasts, magnocellular neurons have a high gain output to increasing contrast but saturate at low to

moderate levels of contrast. Parvocellular neurons have a lower contrast sensitivity than magno neurons and thus do not begin responding until stimulus contrasts have risen to approximately a log unit above absolute threshold. These neurons also exhibit a lower gain than magno mechanisms.

Sturr et al. (1) suggested that age-related differences in brightness function slopes might be due to a reduction in the gain of magnocellular mechanisms of older observers. This conclusion would be on firmer ground if a similar age-related slope difference were observed in perceived contrast functions derived from the viewing of isoluminant grating stimuli, similar to the stimuli employed in studies of LGN mechanisms at the cellular level. Cannon (5, 6) has previously demonstrated dual-branched functions for the perceived contrast of isoluminant grating stimuli in young observers. Thus, at the psychophysical level, there is evidence that parallels the findings at the cellular level. If contrast perception is mediated by the responses of the magno- and parvocellular mechanisms of the LGN, and if a selective attenuation of magno responses occurs with age, perceived contrast functions of young and older observers should resemble the brightness functions shown in Figure 1. The present experiment was therefore designed to measure the perceived contrast functions of young and older observers.

METHODS

Subjects:

Young (ages 17-26 years, mean = 20) and older (ages 60-76 years, mean = 64.5) age groups were composed of 10 male subjects each. The young subjects were screened on the basis of admitted good general and ocular health. Subjects within the older aged group were recruited from local senior citizens activity centers. They were questioned about their medical histories, and their eye care practitioners provided specific information regarding best corrected acuities, lens prescriptions, and the incidence of glaucoma, cataracts, and other ocular pathologies. All older subjects had received an eye examination within 10 months of testing.

All subjects had corrected binocular acuities between 20/20 and 20/25. Three of the older subjects had a slight cataract in one eye; one other subject had mild drusen in one eye. None of these conditions was regarded as severe enough for disqualification from the study. All subjects were paid for their participation in the study.

Apparatus:

Sinusoidal grating patterns of 0.6 c/deg counterphase modulated at 15 Hz and 6.0 c/deg counterphase modulated at 7.5 Hz were generated on a crt (60 Hz noninterlaced, P2 phosphor, mean luminance of 75 cd/m^2) by a Nicolet CS 2000 contrast sensitivity measurement apparatus. These stimulus parameters were selected based on the results of single cell studies (3, 4) and results

from human evoked potential experiments (7). A 0.5 log unit neutral density filter was placed over the monitor screen for the younger subjects, therefore, reducing the screen luminance to 25 cd/m^2. This filter was utilized in order to approximately equate old and young subjects for optical transmission losses found in older individuals (8). Viewing was binocular throughout the study.

Procedure:

Subjects were briefed generally on magnitude estimation procedures and specifically on how to scale the length of line stimuli. The scaling of line stimuli served primarily to train subjects in perceptual scaling. Subjects were instructed to assign numbers, not based on any known standard of measurement, to lines drawn on sheets of paper displayed in front of them (9).

Subjects were seated 1.7 meters from the crt, which subtended a visual angle of 7.5° (wide) X 9.7° (high). Some vision researchers have utilized corrective lenses to equate young and older subjects for the reduced ability of older individuals to accommodate appropriately, particularly for viewing distances of 1 meter or less (8, 10). The viewing distance of 1.7 meters utilized in this study would require a lens of only .58 diopters. While corrective lenses are important for close viewing distances, they were not employed in the present study because the correction would be minor; the highest spatial frequency used was 6.0 c/deg, and the corrective

technique assumes that older observers have a total loss of accommodative power.

The subjects were then instructed on the scaling of stimulus contrasts. The instructions were the same as those used for the line length scaling described above. However, subjects drew a line on a 9 cm (high) by 35.5 cm (wide) sheet of paper instead of producing a number for each stimulus contrast level. Pilot data on young subjects showed that perceived contrast functions were equivalent regardless of whether numbers or line-drawn estimates were used. Since the present study presented subjects with numerous low contrast stimuli, it was determined that line drawn estimates might be advantageous, since subjects tend to report "simple" fractional numbers (1/2, 1/3, 1/4) when estimating stimuli of low intensities[1]. Thus, subjects drew a line, the length of which reflected the magnitude of perceived contrast. Each sheet was labeled with the trial number, and subjects drew a single line on each sheet, then turned the sheet over so that it was out of view.

Each grating was on the screen for approximately 20 seconds[2], and subjects were instructed to keep still and to keep the image focused by occasionally blinking if necessary in order to avoid image fading. An estimate of stimulus contrast was based upon the appearance of the grating throughout its presentation, and the estimate was not made until after the grating had been removed from the screen. After estimating

stimulus contrast, subjects waited approximately 20 seconds for the next trial to begin.

Individual trials always alternated between the two spatiotemporal test frequencies of 0.6 c/deg-15 Hz and 6.0 c/deg-7.5 Hz. Stimulus contrasts were randomized with the restriction that very low contrasts never immediately followed the highest contrasts. The contrast levels measured were 2, 3, 4, 6, 10, 14, 20, 30, and 50 percent, with an extra level of 1% for the 0.6 c/deg-15 Hz condition. The high contrast points (10, 14, 20, 30, and 50 percent) were presented once, while the lower contrast points were presented twice.

Upon the subject's completion of the magnitude estimation procedure, psychophysically determined contrast thresholds were measured for the 0.6 c/deg-15 Hz and 6.0 c/deg-7.5 Hz stimuli. Contrast thresholds were determined in order to quantify the contribution of potential age-related threshold differences on the perceived contrasts of low contrast gratings, for it has been shown that the slopes of perceived contrast functions at lower grating contrast levels are influenced by the contrast threshold (11). The method of increasing contrasts was employed (12): contrast was well below threshold at the outset and increased at a slow rate (0 to 50% in 60 sec), and when the subject first detected the stimulus, he pushed a button on the response box that signaled the computer to record the contrast threshold. This procedure was repeated three times per spatial frequency at each temporal frequency. Three practice trials were included

prior to the threshold measures. A second experiment examining transient evoked potentials in these subjects immediately followed this procedure (13), and the entire session lasted approximately two hours.

Data Reduction Procedure:

Linear functions relating log perceived contrast estimates to log stimulus contrast were fit in a stepwise fashion to each subject's raw data from threshold to approximately 4-8%. Lines were best fit to successively higher contrast points until a break point in the function was reached, as evidenced in a plot of the data and reflected by a decrease in the correlation coefficient compared with linear fits at lower contrasts (1). If a break point was not reached, a line was fit from threshold through 8 percent contrast, the upper limit of the low contrast portion of the perceived contrast function. The slopes of these linear functions served as the low contrast dependent measures in the analyses described below. Linear functions were also fit to the perceived contrast data from 14 to 50 percent contrast in each subject for each stimulus type, the slopes of which served as the high contrast dependent measures.

RESULTS

The psychophysically determined thresholds of the 6.0 c/deg-7.5 Hz and the 0.6 c/deg-15 Hz stimuli were submitted to an AGE GROUP X STIMULUS TYPE split-plot analysis of variance (ANOVA) procedure. The analysis revealed a significant effect of STIMULUS TYPE ($F(1,18)=41.21$, $p<.001$), indicating a greater

sensitivity to the 0.6 c/deg stimulus across all subjects. AGE GROUP was not a significant variable in the threshold analysis. In view of this fact, no further adjustments were made to the contrast estimation data.

Table 1 reports the ANOVA summary statistics for the AGE GROUP X STIMULUS TYPE within CONTRAST LEVEL split-plot analysis on contrast estimation slopes.

Table 1

Analysis of contrast estimation slopes

variables	*s.s.*	*d.f.*	*F values*
AGE	0.13	1	0.32
error	7.19	18	
CONTRAST	8.07	1	47.50***
AGE*CONTRAST	0.12	1	0.71
error	3.06	18	
STIM	0.46	1	4.53*
AGE*STIM	0.23	1	2.26
CONTRAST*STIM	1.76	1	17.26***
AGE*CONTRAST*STIM	0.03	1	0.28
error	3.67	36	

Sums of squares (s.s.), degrees of freedom (d.f.), significance levels:
* p<.05; ** p<.01; *** p<.005.

The only significant component of the analysis was a significant STIMULUS X CONTRAST interaction. This interaction resulted from, across all subjects, a significantly steeper slope for the low contrast 6.0 c/deg stimuli compared with the slope from the high contrast 6.0 c/deg stimuli and both low and high contrast 0.6 c/deg slopes (p=.0001 for each of three comparisons). The AGE GROUP variable was not significant either alone or in

interactions with STIMULUS TYPE or CONTRAST LEVEL. Figures 2 and 3 display subjective estimates of contrast as a function of contrast on log-log coordinates for the 0.6 and 6.0 c/deg stimuli, respectively.

DISCUSSION

The contrast estimation functions of the present study were similar to data reported by Cannon (5, 6, 11) and Gottesman et al. (14). Specifically, the 6.0 c/deg perceived contrast function contained a distinct break point, similar to previously reported contrast (11), and brightness data (1, 2, 15). As Cannon (11) has demonstrated, perceived contrast of stimuli with physical contrasts of approximately 10% or more are equivalent across the spatiotemporal frequency domain. Below physical contrasts of 10%, perceived contrast is generally related to the threshold contrast of a given stimulus, such that perceived contrast functions of high threshold stimuli must rise more steeply to match the perceived contrast of low threshold stimuli. However, this effect is dependent upon the spatiotemporal frequency of the stimulus and may also depend upon the spatial extent of the viewing area. This effect is evident in the present results, which demonstrate that while the 6.0 and 0.6 c/deg gratings of 10% and above were perceived as having nearly equivalent contrast, the significant differences in threshold contrast for these stimuli lead to divergent low contrast limbs of the perceived contrast functions. Clearly, the low contrast portions of the perceived contrast functions for the 0.6 c/deg

stimulus of the present study were not nearly as steep as the low contrast limbs of the 6.0 c/deg functions. It is conceivable that the steeper perceived contrast functions for high threshold stimuli shown in this and other experiments might be the result of processing by the high gain magnocellular visual mechanisms.

The slopes of the contrast estimation functions showed remarkable agreement between young and older subjects at low contrast levels. From these data, it is apparent that near-threshold visual mechanisms are operating similarly within these age groups under the conditions used in this study. The age-related differences found by Sturr et al. (1) for perceived brightness of low intensity, brief flashes, did not generalize to isoluminant gratings presented over many seconds. Our results and those from a contrast matching study by Tulunay-Keesey, Ver Hoeve, and Terkla-McGrane (16) suggest that suprathreshold contrast perception is generally equivalent across the lifespan.

The age-related changes in perceived brightness reported by Sturr et al. (1) for brief flashes may be due in part to the inability of the senescent visual system to respond or adapt quickly to step function changes in mean luminance. Clearly, the largest age-related changes in sensitivity occur when a test flash must be detected against a flashing background (17, 18, 19) or when a critical detail must be detected in a flashed pattern (20). Under isoluminant conditions, Sturr, Church, and Taub (10) demonstrated that young and older observers have equivalent

thresholds to grating stimuli presented for durations as brief as 17 msec. Thus, apart from age-related threshold differences found by Owsley et al. (8) and Tulunay-Keesey et al. (15) for temporally modulated high spatial frequency stimuli[3], visual performance of young and older observers on threshold and suprathreshold tasks may be nearly equivalent under isoluminant stimulating conditions, so long as age-related optical transmission differences are considered.

The results of the present study are not supportive of the hypotheses of age-related changes in LGN magnocellular processing. It remains to be determined whether our long stimulus duration precluded the detection of age-related differences in perceived contrast. However, the results of this and other studies suggest that age-related changes in visual sensitivity and perception are most distinguished when mean luminance is modulated in a step function over time.

FOOTNOTES

1. Subsequent pilot investigations have determined that line drawn estimates offered no advantage over numerical estimates even at low contrast levels. However, when using the numerical method of estimation, low intensities or contrasts should be presented several times to each subject, since subjects may use different fractional values for the same low contrast stimulus, and the average estimates avoid the "stepping" problem associated with estimation by common fractions.
2. The contrast estimates were collected simultaneously with visual evoked potentials, thus the need for a long viewing time. The evoked potential data did show a complex age-related difference at high contrast levels that, when considered with the results presented in this paper, might suggest preserved high contrast perception with age despite neural changes within the elderly brain. However, the high contrast evoked potential results were complex and would not contribute to the issues addressed in this study. For a full discussion of this data, see Van Orden (21).
3. The method used by Tulunay-Keesey et al. (von Bekesy tracking) may have been more sensitive to age-related differences in threshold compared with the method of increasing contrasts used in the present study. Other differences between their study and ours include the use of

a 0.5 log unit neutral density filter for our younger observers and our use of male observers exclusively.

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FIGURE LEGENDS

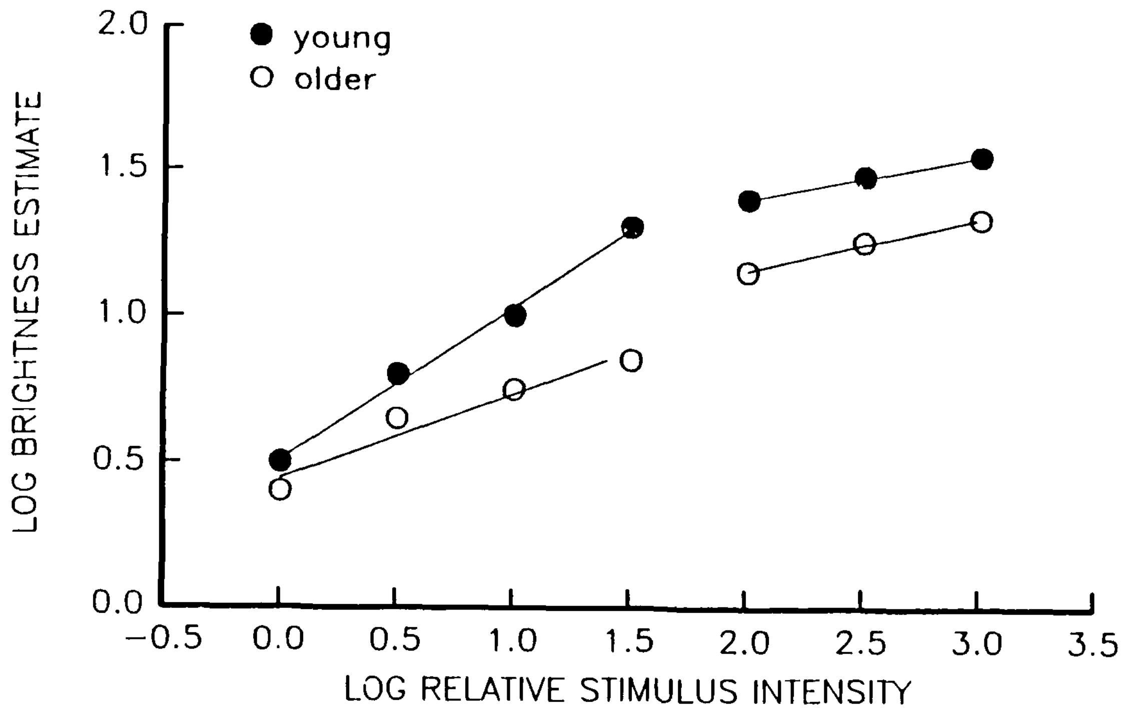
Figure 1. Log brightness estimates plotted as a function of log relative stimulus intensity for combined durations of 10, 100, and 1000 msec. Young subjects (n = 10) are represented by filled circles, older subjects (n = 10) by open circles. Low intensity data (first four points) and high intensity data (last three points) were fit by the method of least squares. 0 log intensity = 0.068 cd/m^2 for the young, and 0.216 cd/m^2 for the older subjects. Data replotted from Sturr, Van Orden, and Taub (1).

Figure 2. Estimates of contrast in millimeters as a function of percent stimulus contrast for the 0.6 c/deg-15 Hz condition. Young subjects' data are represented by open circles, older subjects' data by filled triangles. Lines represent mean functions fit to low and high contrast portions of the data from each group. Slope means for young subjects: low contrast slope = 0.86, high contrast slope = 0.64. Slope means for older subjects: low contrast slope = 1.01, high contrast slope = 0.55. The design standard error for the contrast estimation slopes was 0.101.

Figure 3. Estimates of contrast in millimeters as a function of percent stimulus contrast for the 6.0 c/deg-7.5 Hz condition. Slope means for young subjects: low contrast slope = 1.46, high contrast slope = 0.57. Slope means for older subjects: low contrast slope = 1.31, high contrast slope = 0.34.

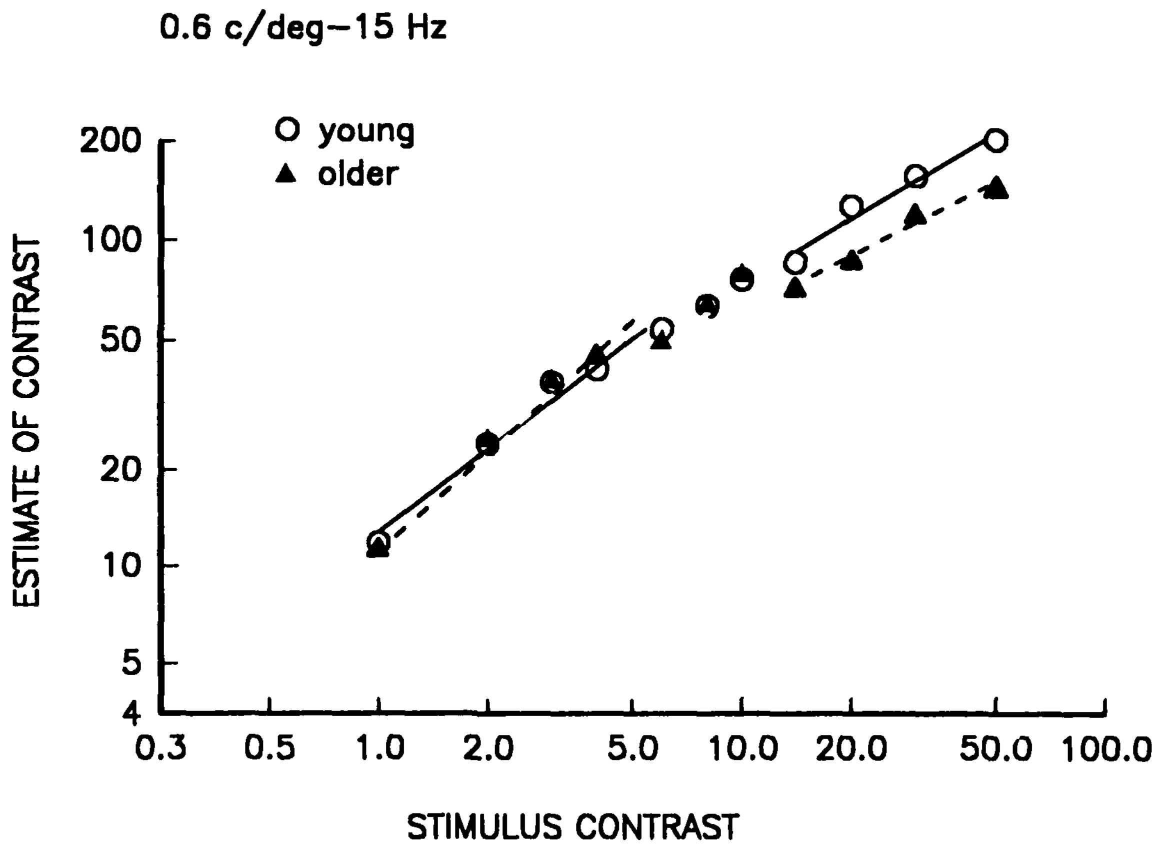
APPENDIX

FIGURE 1



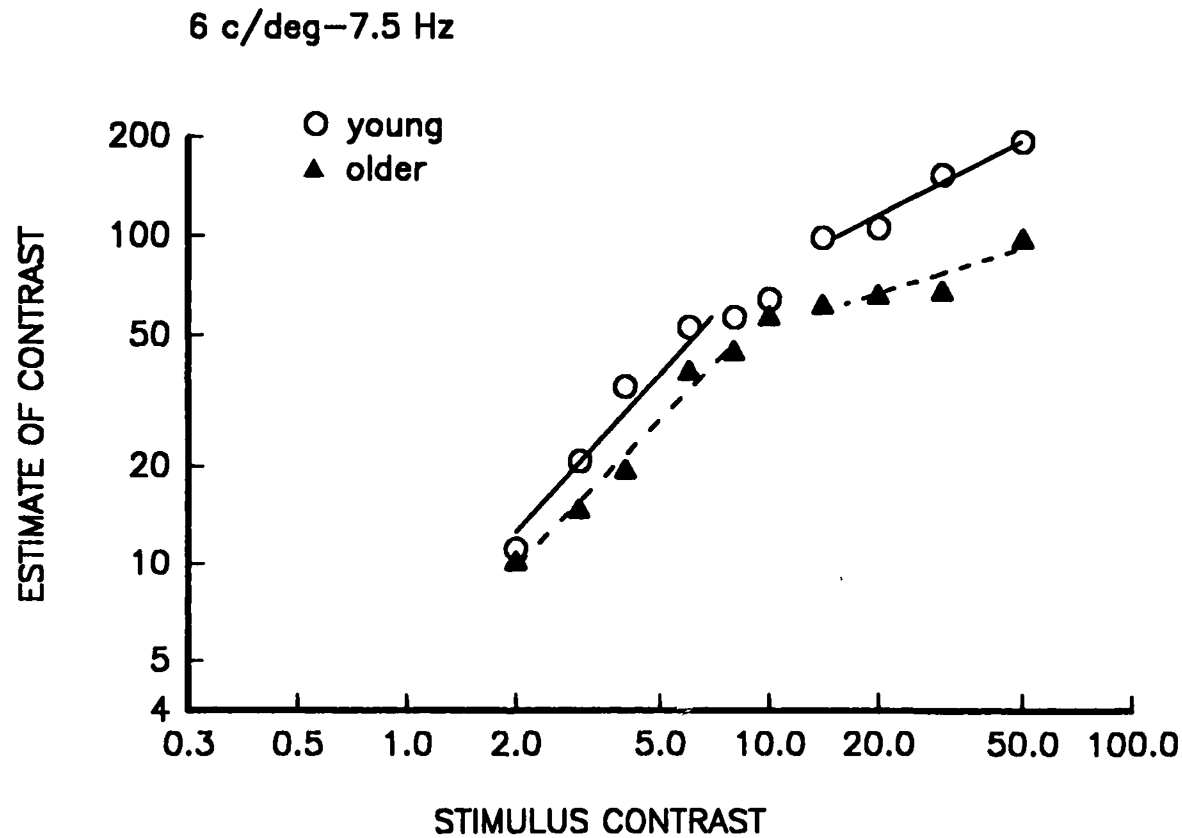
young
older
2.0
1.5
1.0
0.5
0.0
LOG BRIGHTNESS ESTIMATE
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
LOG RELATIVE STIMULUS INTENSITY

FIGURE 2



0.6 c/deg—15 Hz
young
older
200
100
50
20
10
5
4
0.3
0.5
1.0
2.0
5.0
10.0
20.0
50.0
100.0
ESTIMATE OF CONTRAST
STIMULUS CONTRAST

FIGURE 3


6 c/deg—7.5 Hz
○ young
▲ older
200
100
50
20
10
5
4
0.3
0.5
1.0
2.0
5.0
10.0
20.0
50.0
100.0
ESTIMATE OF CONTRAST
STIMULUS CONTRAST